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Natural Frequencies and Mode Shapes of the Bridge over the Kocher-Valley

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The measuring method used to detect natural frequencies and modes is based on the excitation of the considered building by traffic, wind and natural microtremors. Any motion of a building can be considered as a sum of a large number of natural modes, vibrating with distinct amplitudes and at different frequencies, the natural frequencies. It is possible to detect these frequencies and modes by recording time-history-signals of the points of interest in the building for a sufficient period of time. These signals have to be processed by a spectrum analyzer, which computes transfer functions and spectral densities of the signals in the frequency domain and makes it possible to determine natural frequencies and to calculate corresponding mode shapes.

The advantage of this method is that no artificial excitation is necessary, so that measurements can be performed on completed buildings in full use without any damage and without having to interrupt work, as well as on structures in any stage of completion. It is of utmost importance to be able to check calculations of the vibration behaviour in order to ensure the earthquake resistance of the structure.

The mechanical model for the calculation of vibration characteristics concentrates masses and moments of inertia at the tops of the 8 pillars. Considering the different bearings, there remain 31 degrees of freedom for the whole system. The mass matrix was gained by a proper estimation of the contributing parts of pillars and girder. The stiffness matrix for the chosen degrees of freedom was calculated accurately by methods common in building statics. Three versions were calculated: Version 1 considered only the mass of the girder, version 2 in addition the pillar masses and the moments of inertia, version 3 contained the influence of axial forces in the pillars.

The measuring method presented here was found reliable not only in the presented example of a large bridge which is a comparatively rigid structure with very low natural frequencies, but also in several highrise buildings and in the very rigid structure of a nuclear power plant. This is of main interest for the earthquake resistance of buildings. Another application of this method could be to monitor prestressed concrete bridges. An eventual loss of stiffness would influence the natural frequencies as well as the mode shapes of the structure; see the inserted beam example. This loss of stiffness can be detected by using periodical measurements with the presented method which allows the determination of the natural frequencies with great accuracy.

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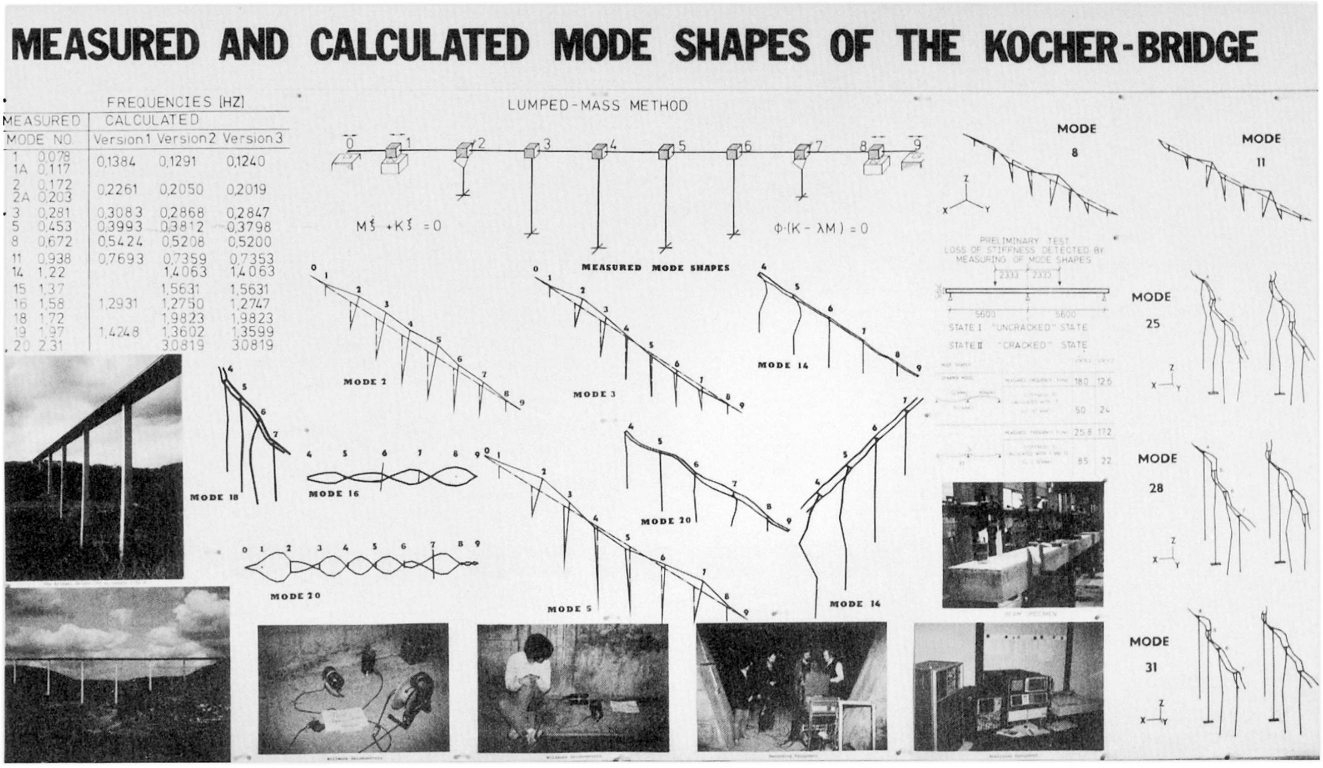
MEASURED AND CALCULATED MODE SHAPES OF THE KOCHER-BRIDGE
FREQUENCIES [HZ]

MEASURED		CALCULATED		
MODE NO.		Version 1	Version 2	Version 3
1	0,078	0,1384	0,1291	0,1240
1A	0,117			
2	0,172	0,2261	0,2050	0,2019
2A	0,203			
3	0,281	0,3083	0,2868	0,2847
5	0,453	0,3993	0,3812	0,3798
8	0,672	0,5424	0,5208	0,5200
11	0,938	0,7693	0,7359	0,7353
14	1,22		1,4063	1,4063
15	1,37		1,5631	1,5631
16	1,58	1,2931	1,2750	1,2747
18	1,72		1,9823	1,9823
19	1,97	1,4248	1,3602	1,3599
20	2,31		3,0819	3,0819

LUMPED-MASS METHOD
$M\ddot{\xi} + K\xi = 0$
$\Phi(K - \lambda M) = 0$
MEASURED MODE SHAPES
MODE 2
MODE 3
MODE 14
MODE 18
MODE 16
MODE 20
MODE 20
MODE 5
MODE 14
MODE 8
MODE 11
PRELIMINARY TEST
LOSS OF STIFFNESS DETECTED BY
MEASURING OF MODE SHAPES
STATE I "UNCRACKED" STATE
STATE II "CRACKED" STATE
MODE 25
MODE 28
MODE 31